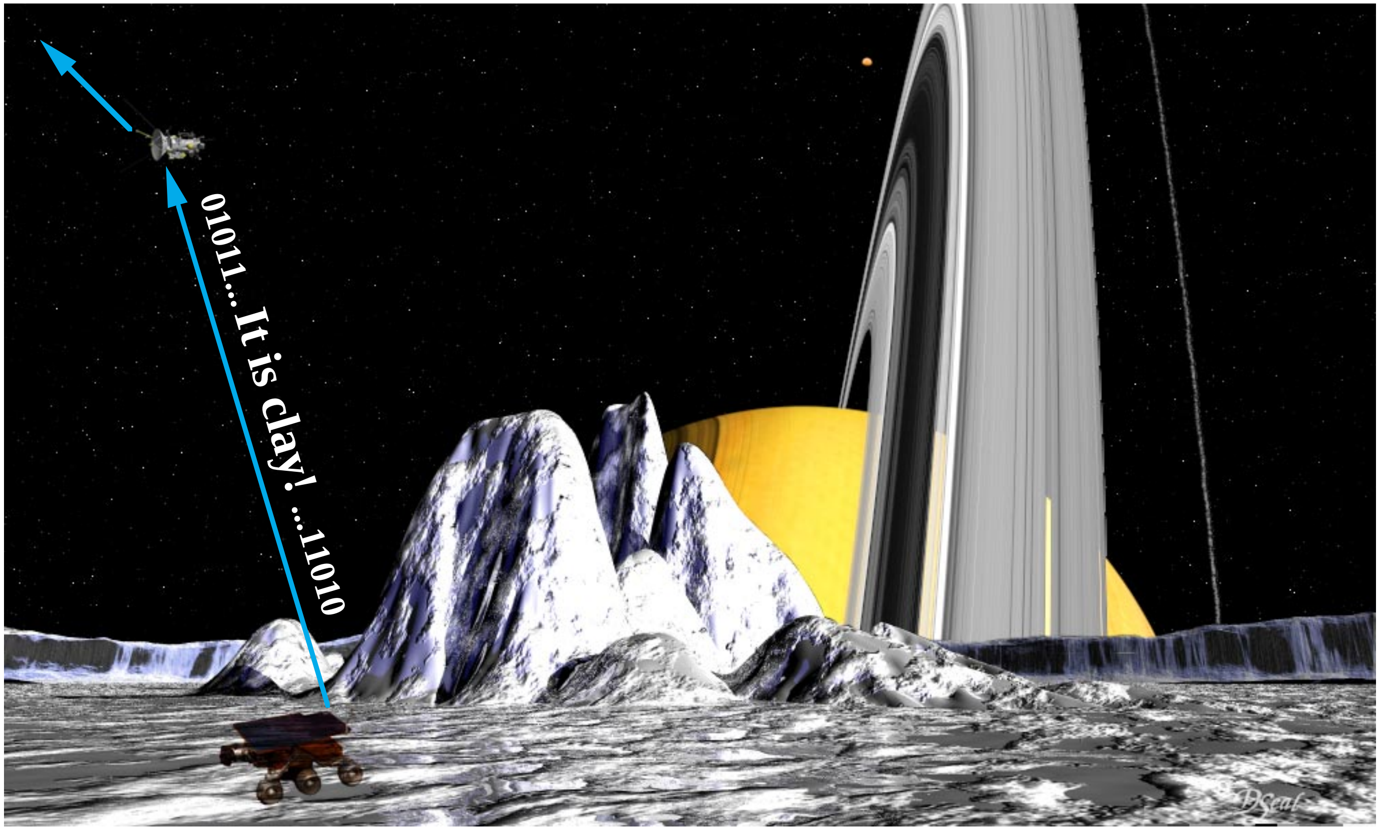
NEW MILLENNIUM PROGRAM
LECTURE SERIES

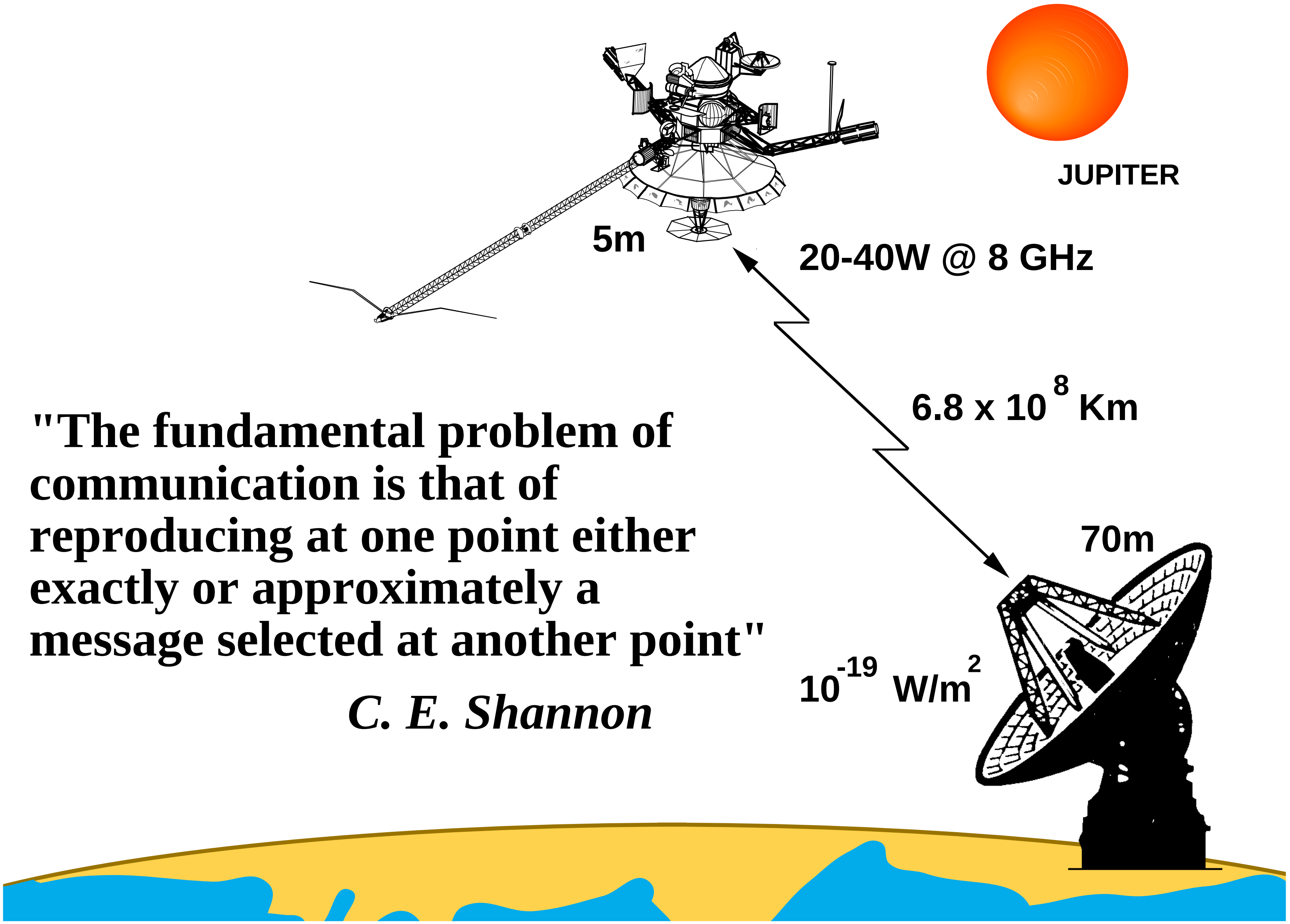
Monday, June 10, 1996

"SQUEEZING OUT MORE INFORMATION ON A LOW BUDGET"



Fabrizio Pollara

Communications Systems and Research Section (331)

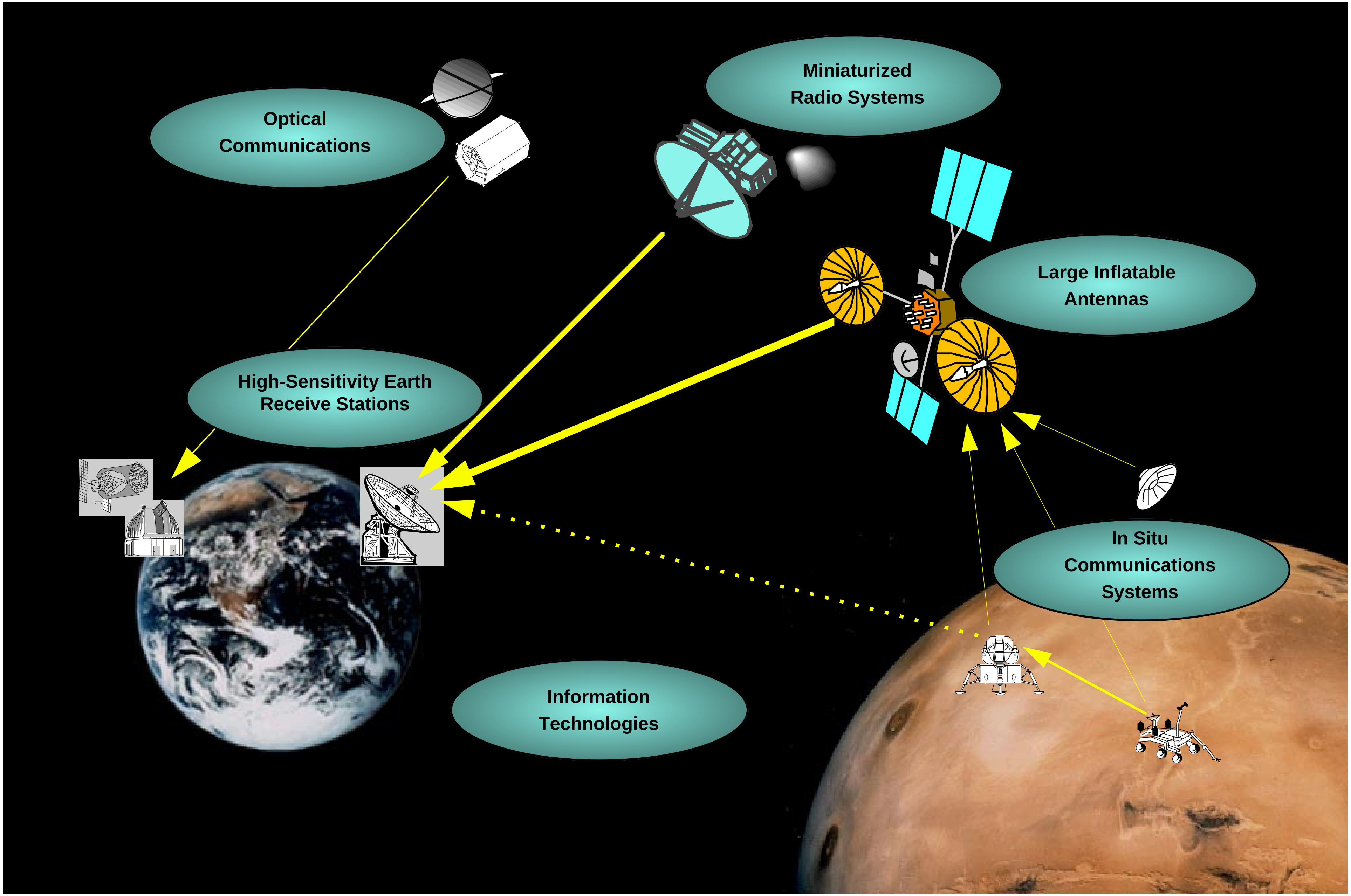


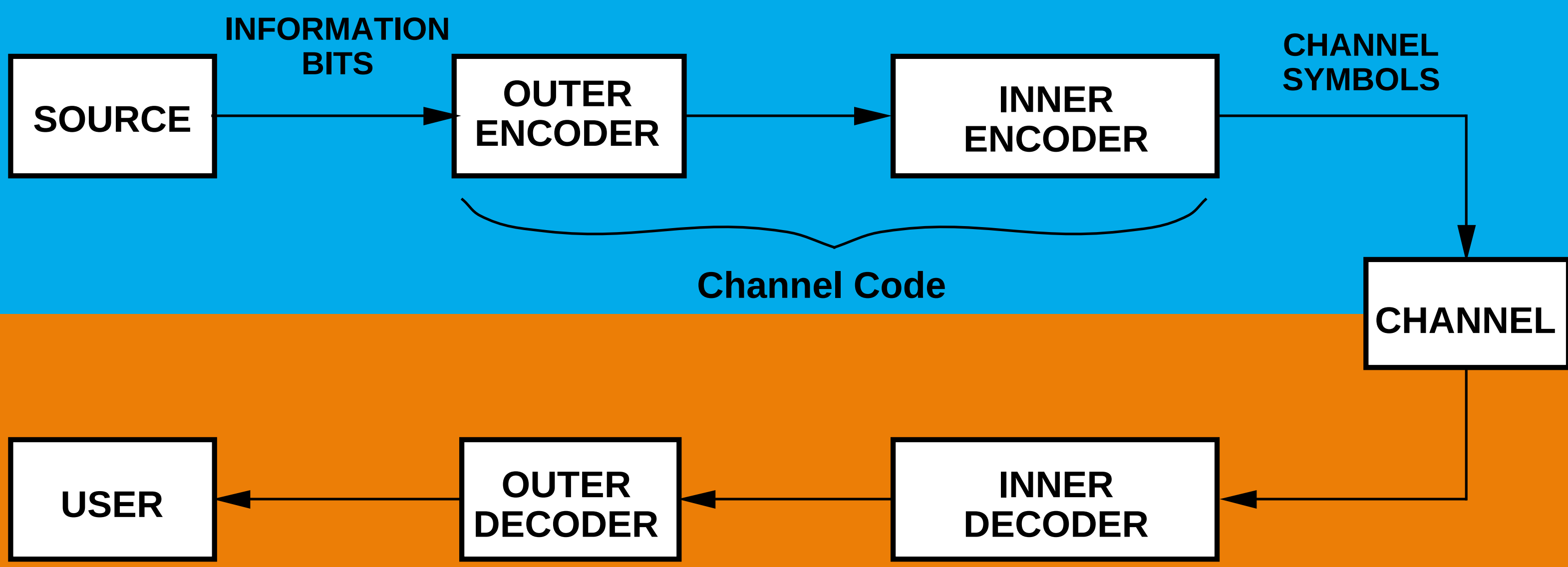
"The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point"

C. E. Shannon

New Millennium Lecture

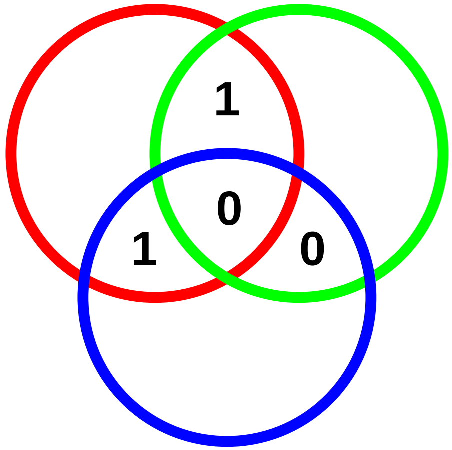
NASA Space Communications

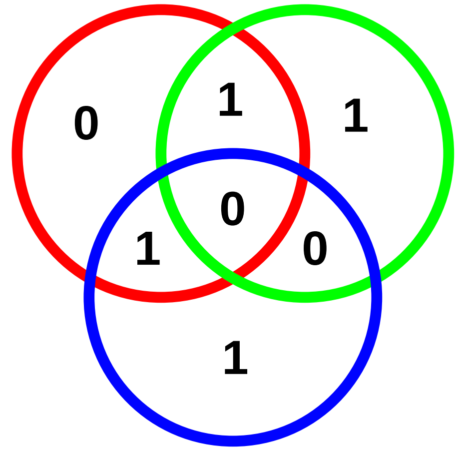




COMMUNICATION SYSTEM MODEL WITH CONCATENATED CODING

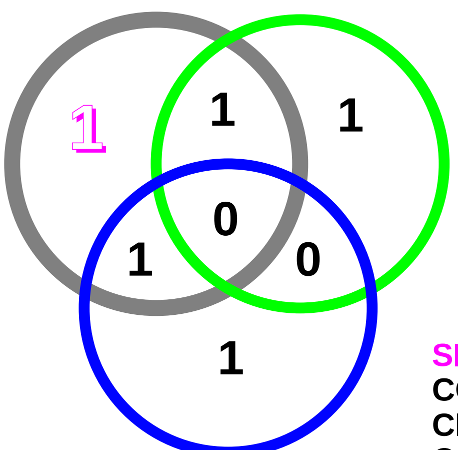
AN EXAMPLE OF ERROR-CORRECTION CODING: THE (7,4) HAMMING CODE



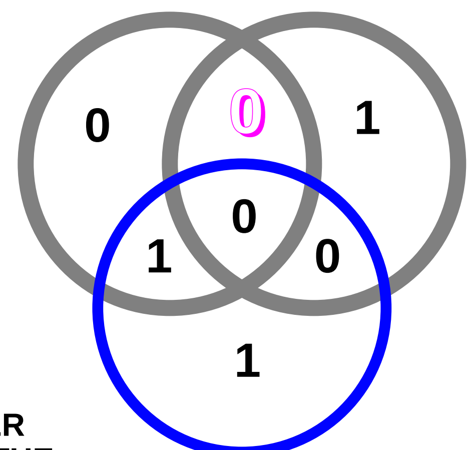


4 INFORMATION BITS ARE PLACED IN THE INTERSECTIONS OF THE VENN DIAGRAM

EACH CIRCLE IS FILLED WITH A "PARITY BIT" TO FORM A 7-BIT CODEWORD



SINGLE ERRORS CAN BE CORRECTED BY FINDING THE CIRCLES WITH AN ODD NUMBER OF 1'S AND COMPLEMENTING THE BIT IN THEIR INTERSECTION



Error correction coding reduces the required transmitter power for a fixed data rate (or increases the data rate for a fixed transmitter power) for a desired reliability (residual bit error rate)

This is possible because the redundancy introduced by coding is more than offset by its ability to correct a certain amount of errors

The (7,4) Hamming code can correct only one error in a block of seven symbols!

Much more powerful codes have been used in JPL missions:

(7,1/2) convolutional code	Voyager
(7,1/2) code + Reed-Solomon code	Voyager at Neptune
(15,1/4) code + Reed-Solomon code	Galileo (Original plan)
(15,1/6) code + Reed-Solomon code	Cassini

However, further improvements were beyond reach due to enormous increase of decoder complexity ...

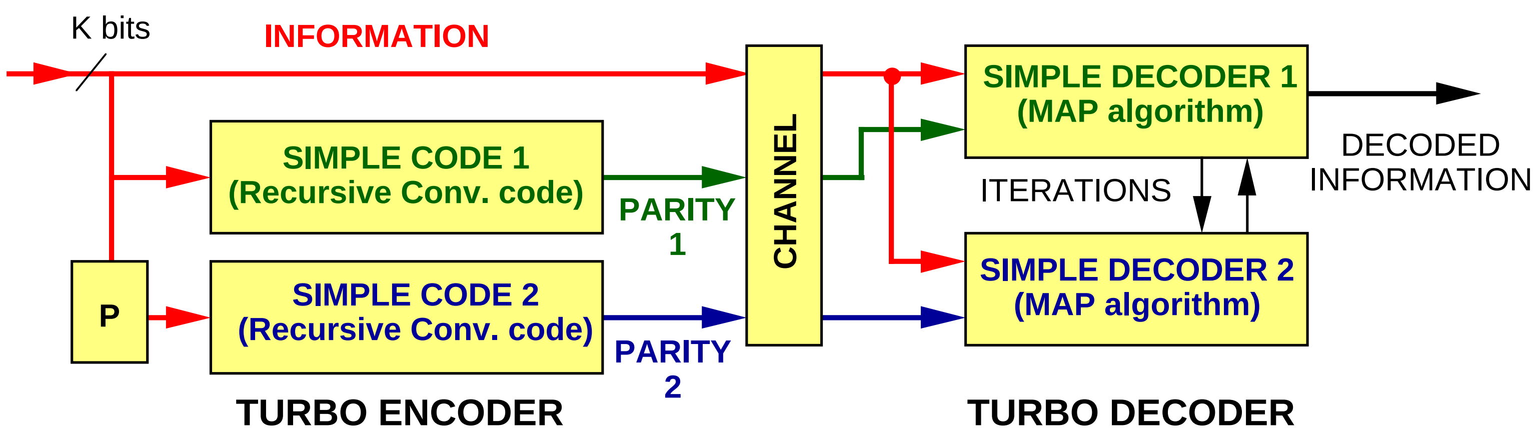
....until recently!

Turbo Codes for Deep-Space Communications

A turbo code is a combination of two simple codes.

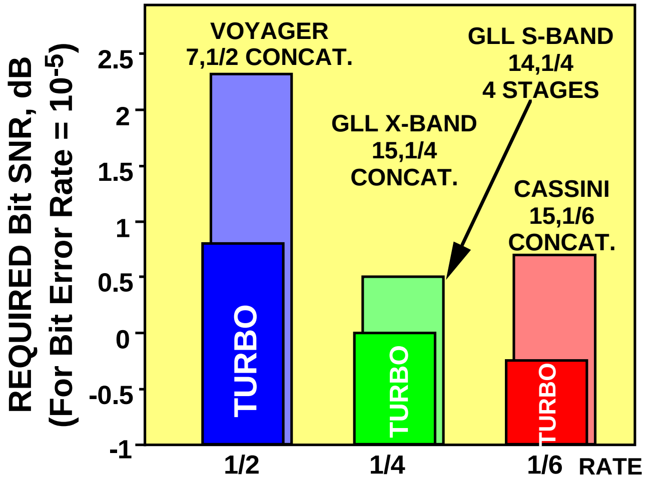
For a block of K information bits, each constituent code generates a set of parity bits.

The turbo code consists of the information bits and both sets of parity.



Turbo codes represent a quantum leap in channel coding performance for deep space applications, providing higher coding gain and much lower decoding complexity than current coding systems

Turbo Codes for Deep-Space Communications
Performance and complexity



CODE PERFORMANCE

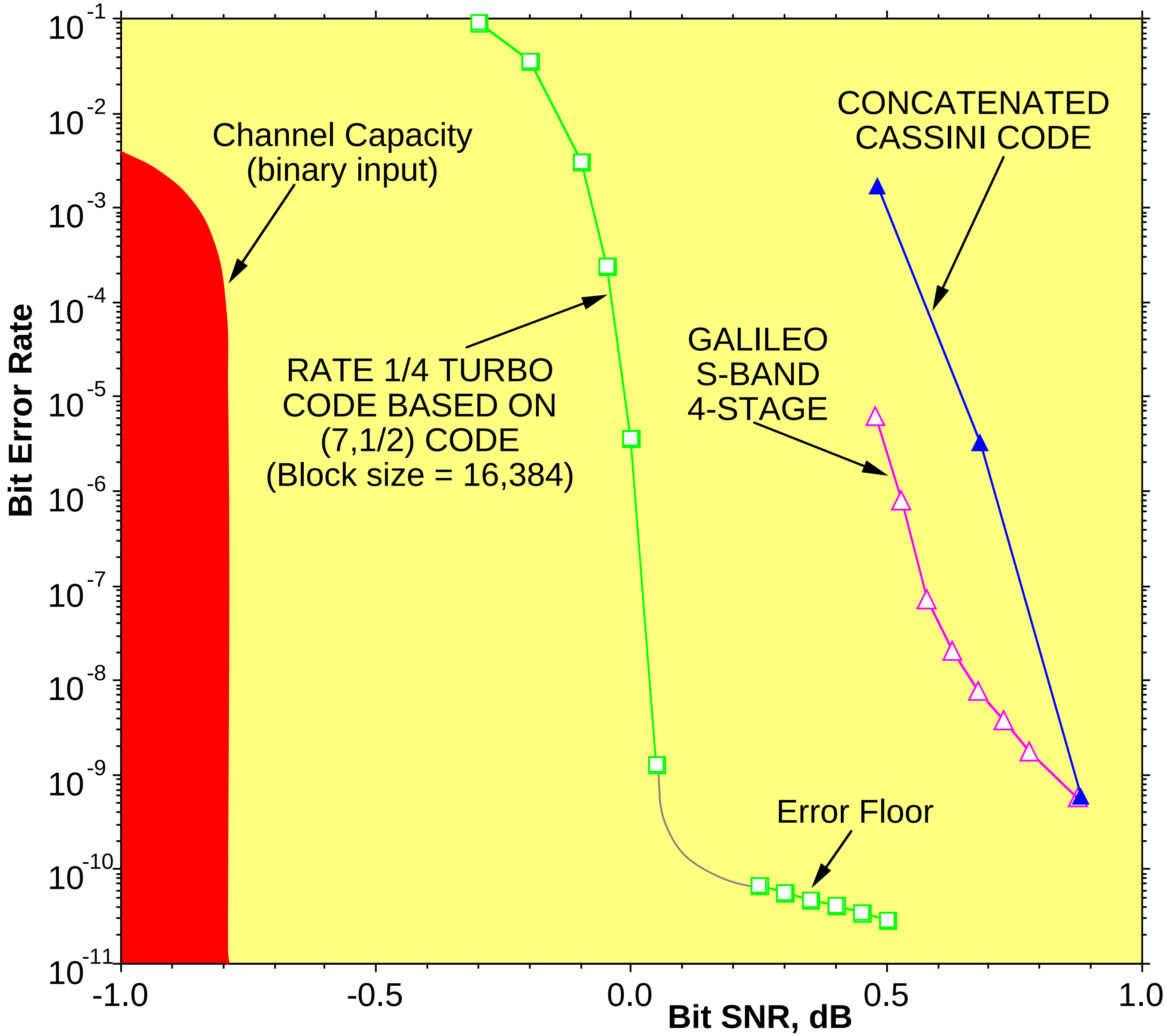
- **Turbo codes outperform the codes currently used in NASA's deep-space missions**
- **They are much simpler to decode than the Galileo and Cassini codes**

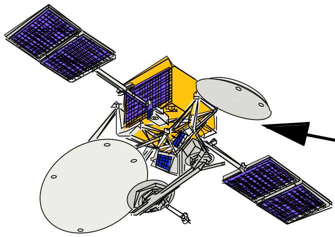
- **The decoding complexity scales as the number of states times the number of iterations**
- **To achieve their phenomenal performance, turbo codes require the use of large interleavers, but not much larger than those used by current concatenated codes**

	NO. OF STATES	NO. OF ITERATIONS	RELATIVE COMPLEXITY
TURBO	16+16	10	1
GLL X-BAND	16,384	1	51
GLL S-BAND	8,192	4	102
CASSINI	16,384	1	51

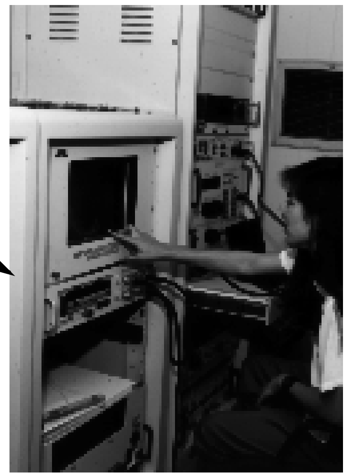
DECODING COMPLEXITY

Comparison of turbo codes with current coding schemes

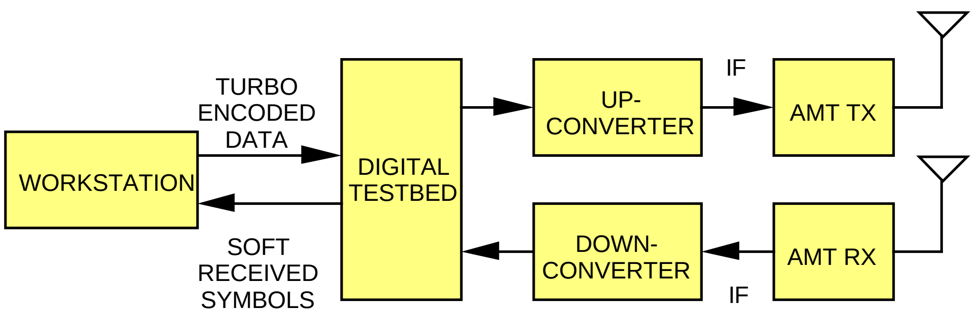




- Rate 1/2 turbo code
- 16,384-bits code block
- QPSK modulation with differential detection

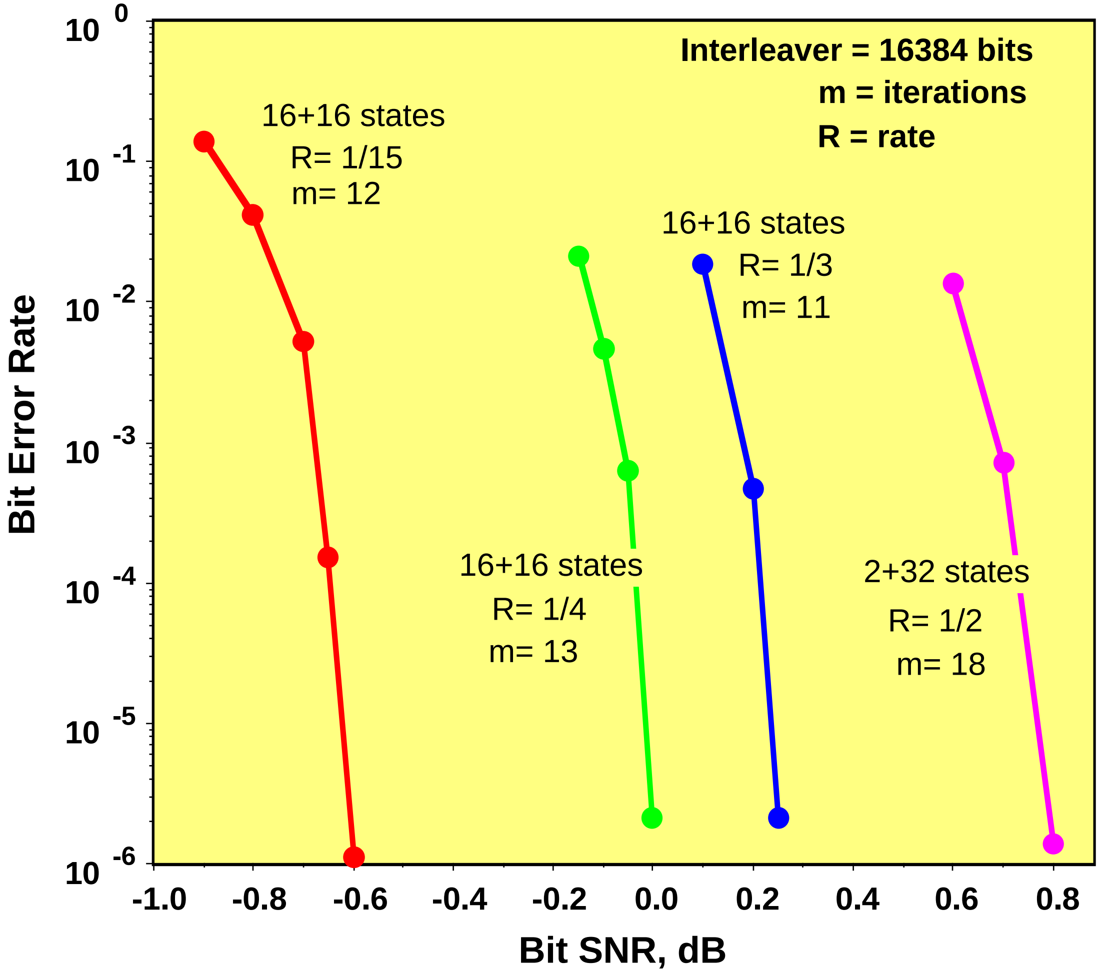


Turbo codes have been demonstrated on a real channel in TDL (Telecommunications Development Lab)

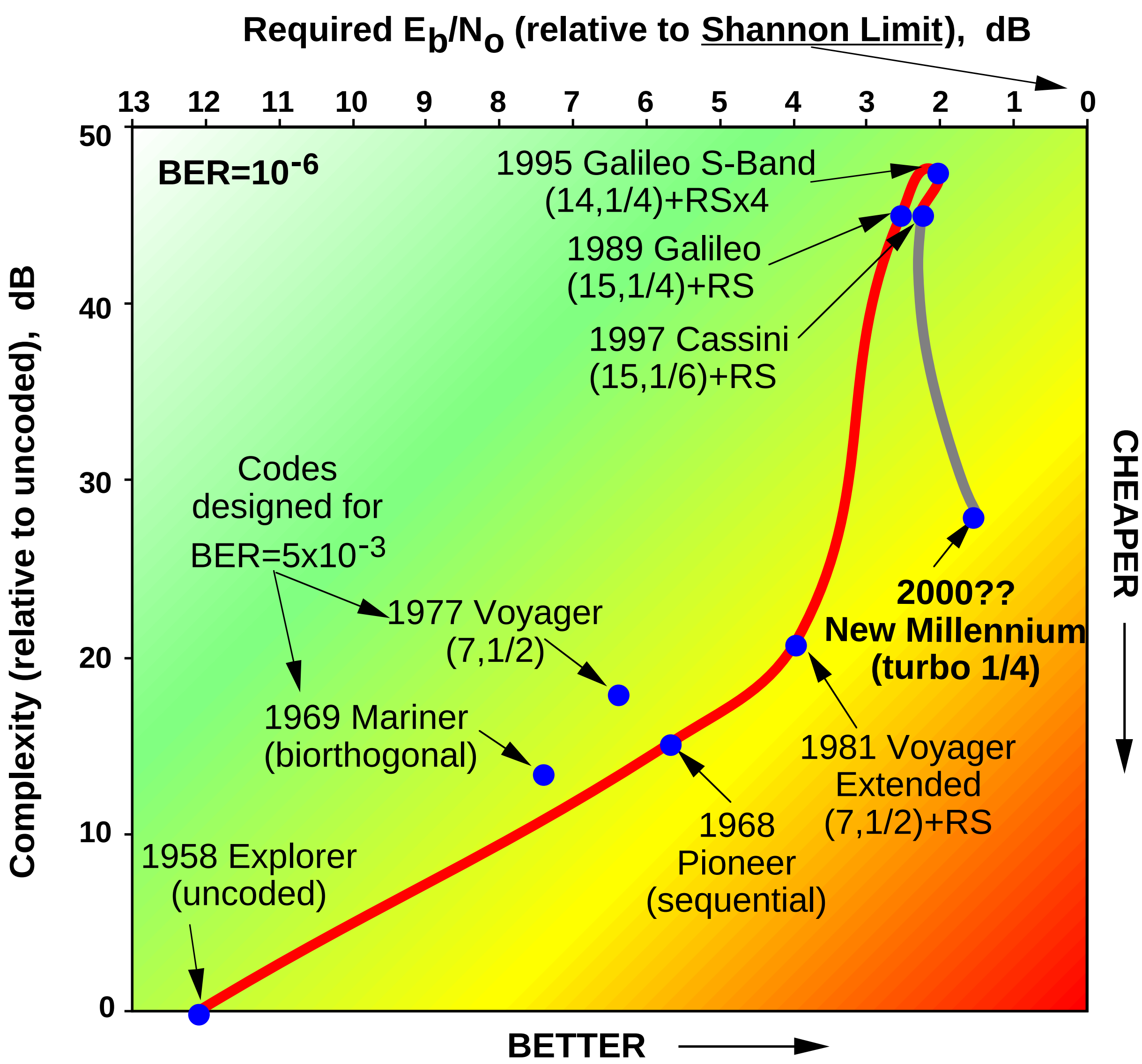


An experiment on a space link using ACTS is in progress

Performance of New Turbo Codes

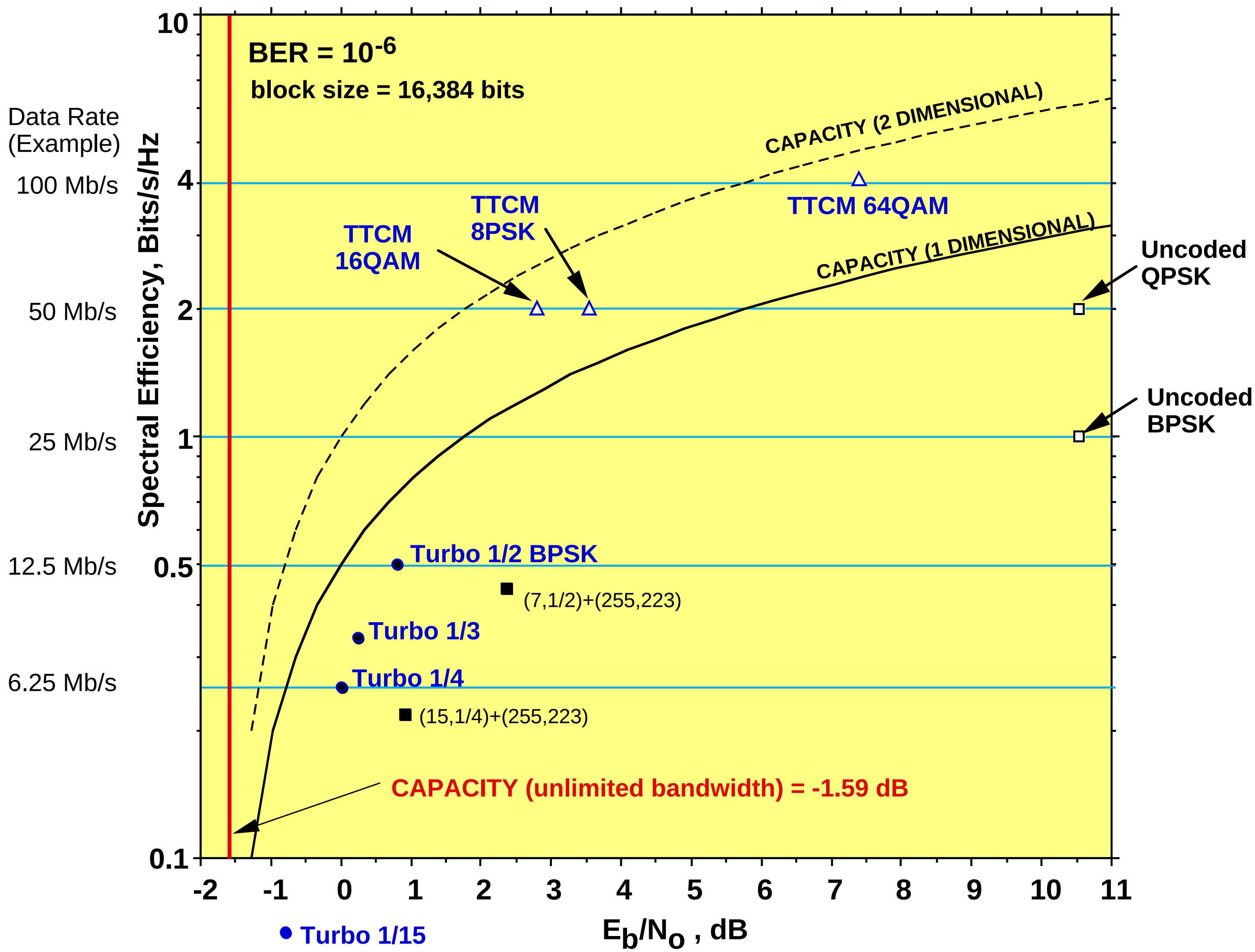


Evolution of channel coding systems used for deep-space communications



- **The turbo code structure was extended to develop codes that are power efficient <u>and</u> bandwidth efficient**

Example: X-band link, 50 MHz allocation




IF NEW MILLENNIUM WON'T USE OUR TURBO CODE IDEA LET'S QUIT AND START OUR OWN BUSINESS!
WHY QUIT? WE CAN RUN OUR NEW COMPANY FROM OUR CUBICLES AND GET PAID TOO.
WOULDN'T THAT BE IMMORAL?
THAT'S ONLY AN ISSUE FOR PEOPLE WHO AREN'T ALREADY IN HELL.
S. Adams E-mail: SCOTTADAMS@AOL.COM
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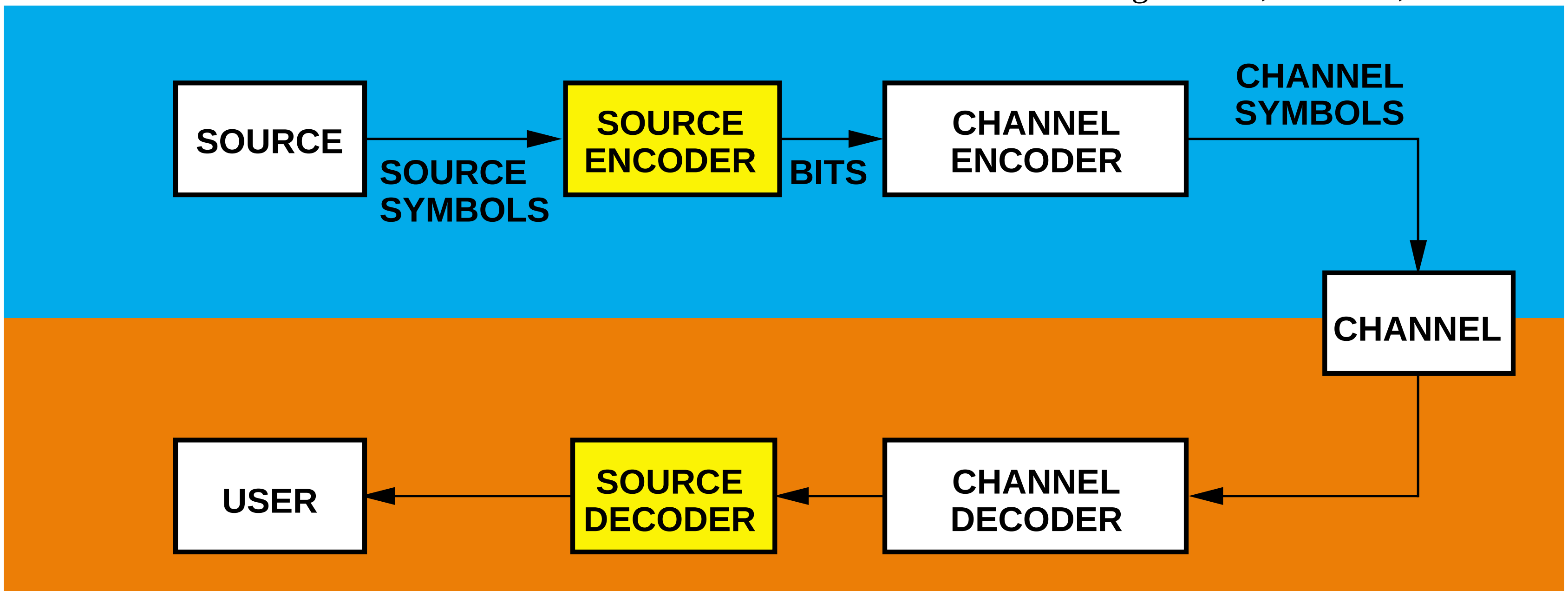
... Compression is an obscure discipline, a world of tedious lab work, academic conferences and acronyms such as MPEG and ADSL. But already it is letting companies bring to market products once dismissed as being years away ...

The Washington Post, Nov. 28, 1993



CODED COMMUNICATION SYSTEM MODEL

- **Data compression conserves transmission (or storage) bandwidth by removing redundancy in the source**
- **Error correction introduces suitable redundancy to control channel errors**
- **Source/channel coding interaction (error propagation; error containment)**

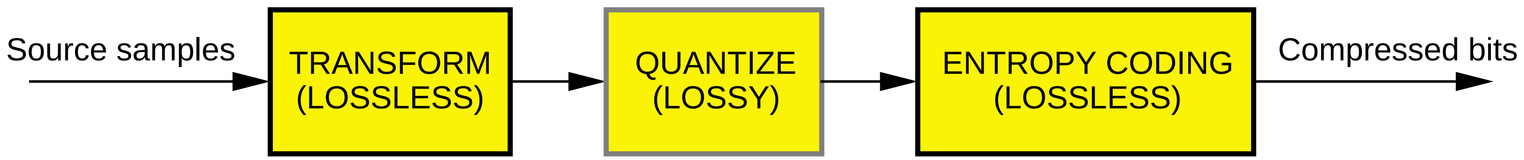
Data Compression Methods

Entropy Coding

Variable length coding (e.g., Huffman coding): Assign shorter codewords to more probable symbols

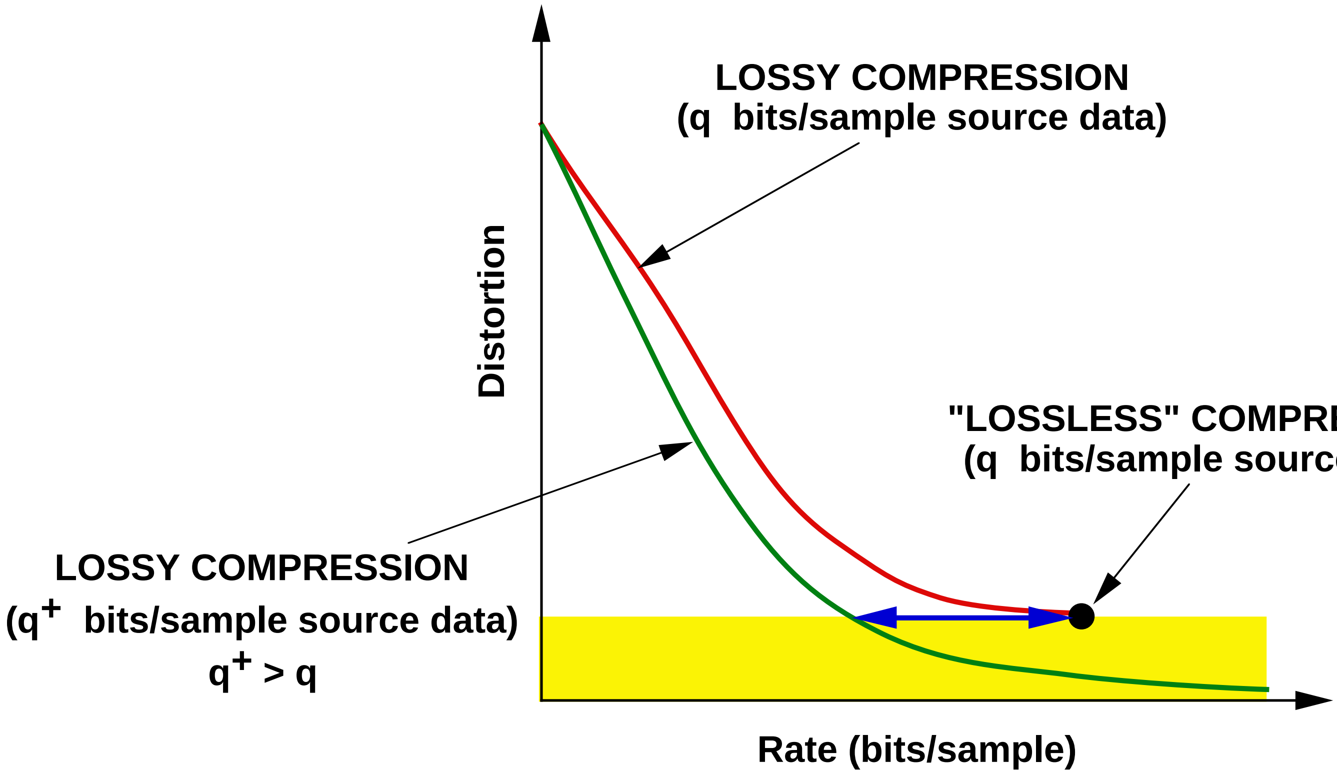
Arithmetic coding: Improved performance, higher complexity

Transform Based Compression



Transform stage decorrelates data, making compression stage more efficient. Examples: WHT, DCT (JPEG), Subband Coding (wavelets), ICT, DPCM

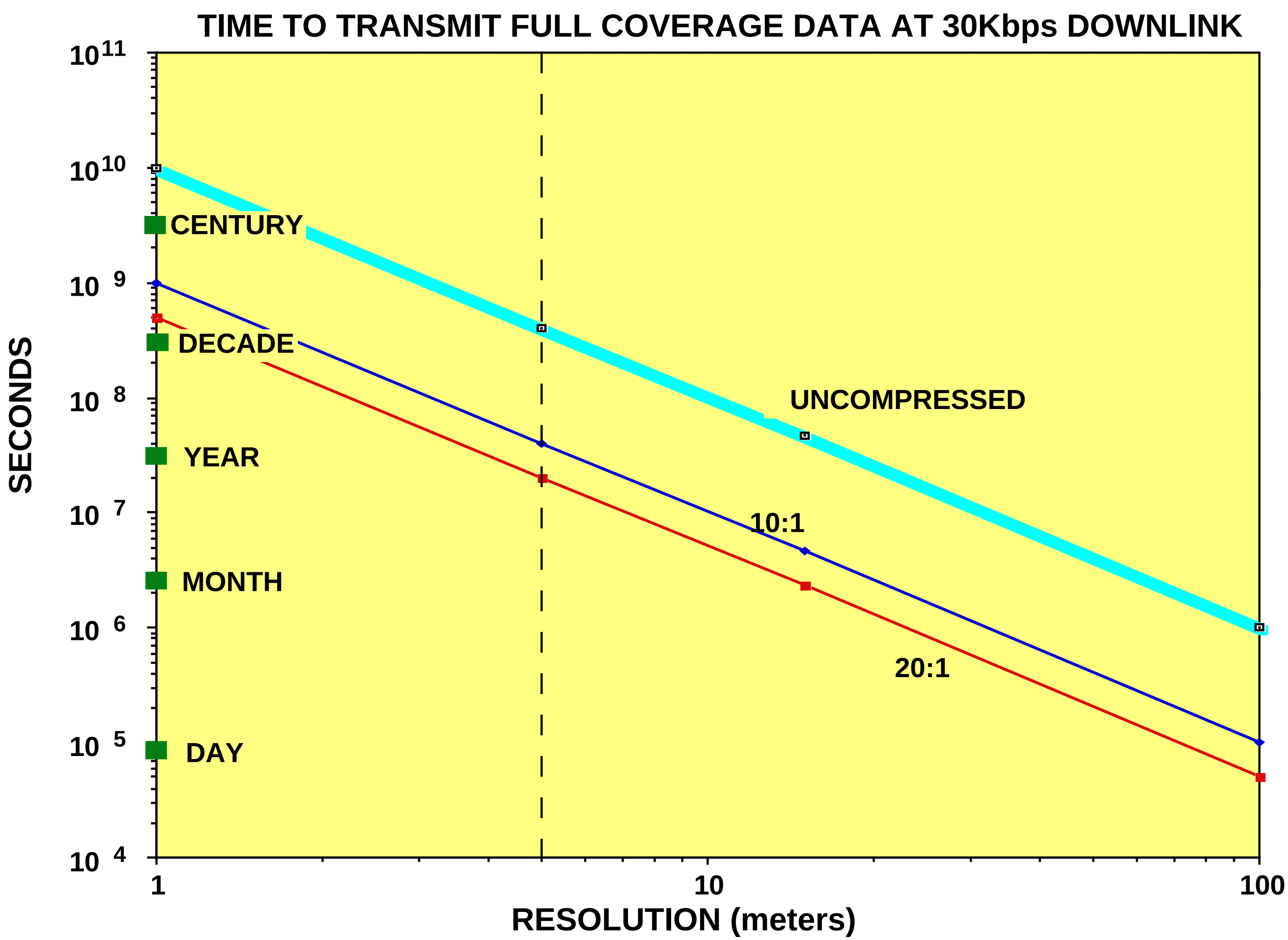
Data compression is good
(... but don't touch my bits!)



A typical rate-distortion curve

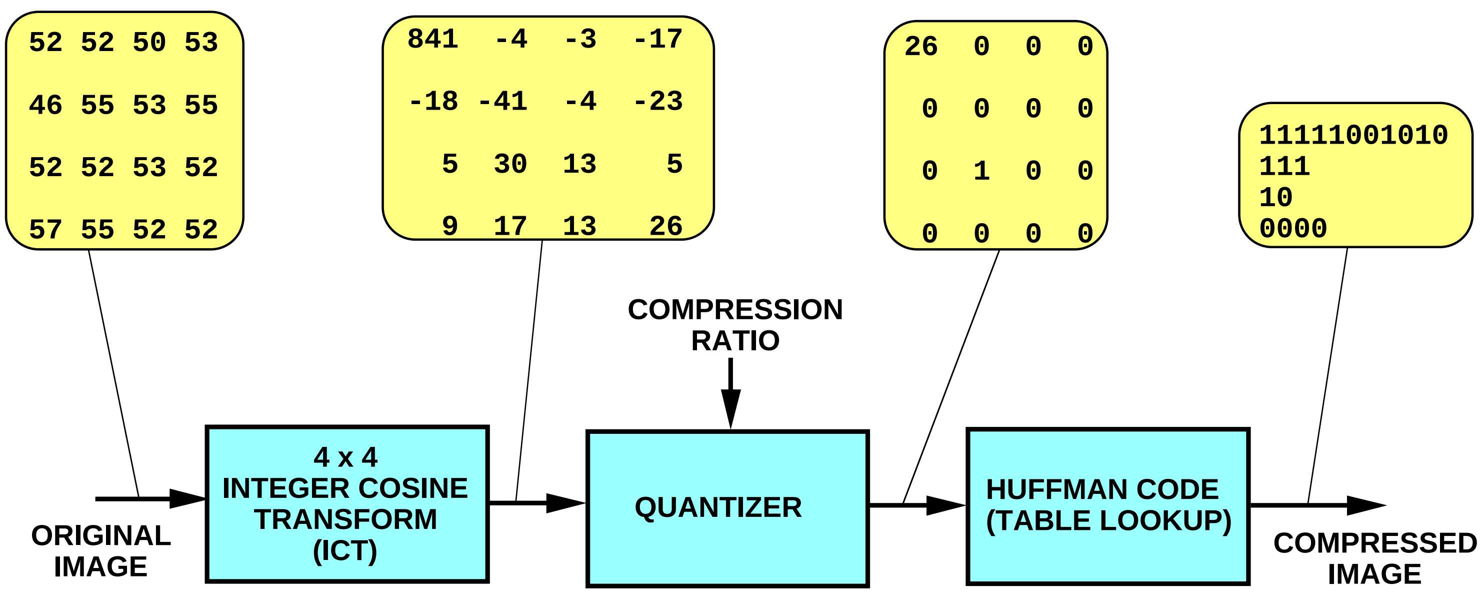
BENEFITS OF COMPRESSION SCHEMES ON DATA RETURN

(Example: Imaging mission to the moon)



- **Developed the data compression algorithm that is used in the Galileo S-band mission (After the the high gain antenna anomaly)**
  - **This algorithm is based on an low-complexity transform, the integer cosine transform (ICT)**
  - **Its low complexity is also desirable for small spacecraft**

A 4x4 example of the ICT compression algorithm used by Galileo S-band



Progressive image transmission using subband coding (Wavelets)

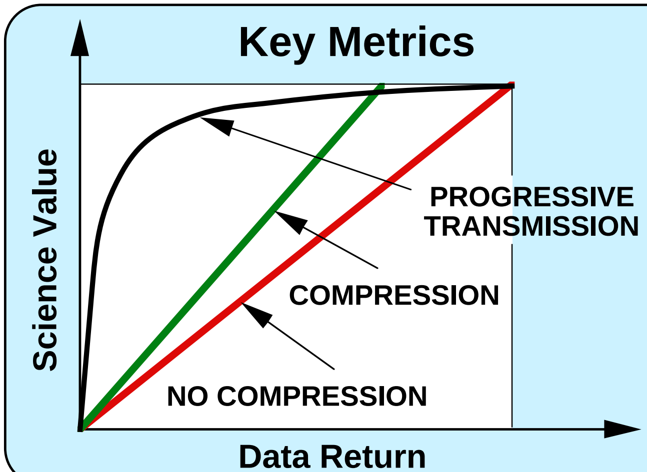
Goal was to produce high quality images at intermediate resolutions

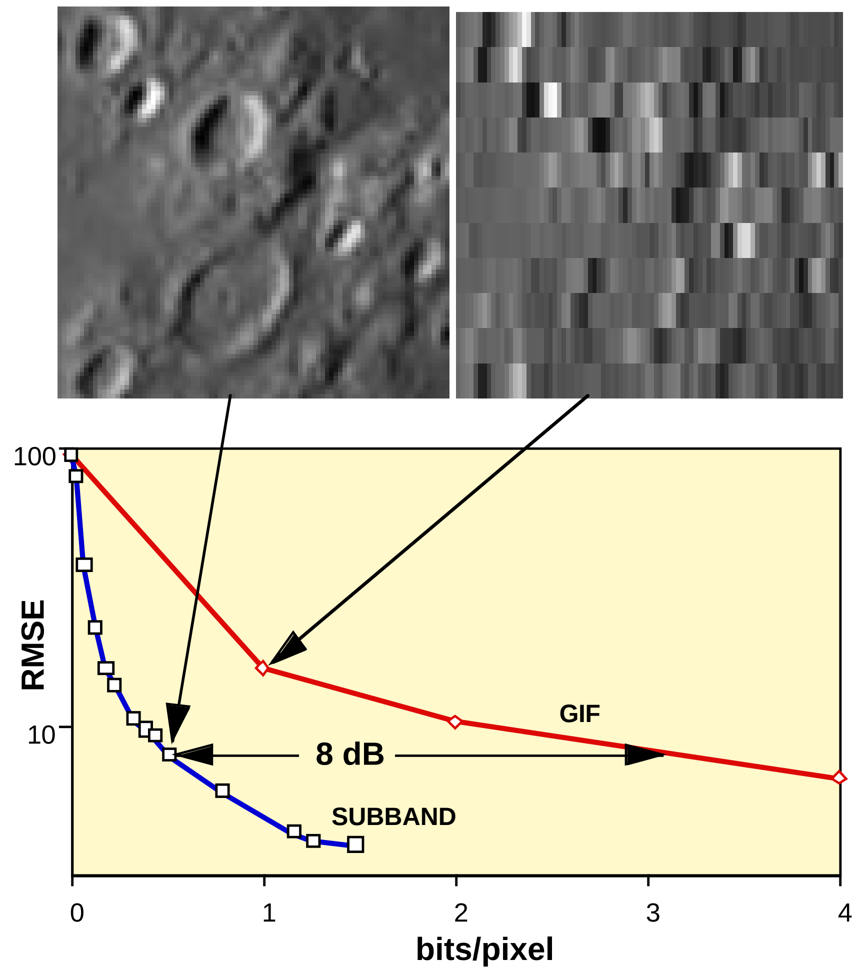
<u>Advantages of subbang coding method:</u>

Delivers a good quality image at 0.5 bits/pixel while GIF requires 3.3 bits/pixel for same quality

Delivers an essentially lossless image at much lower data rate

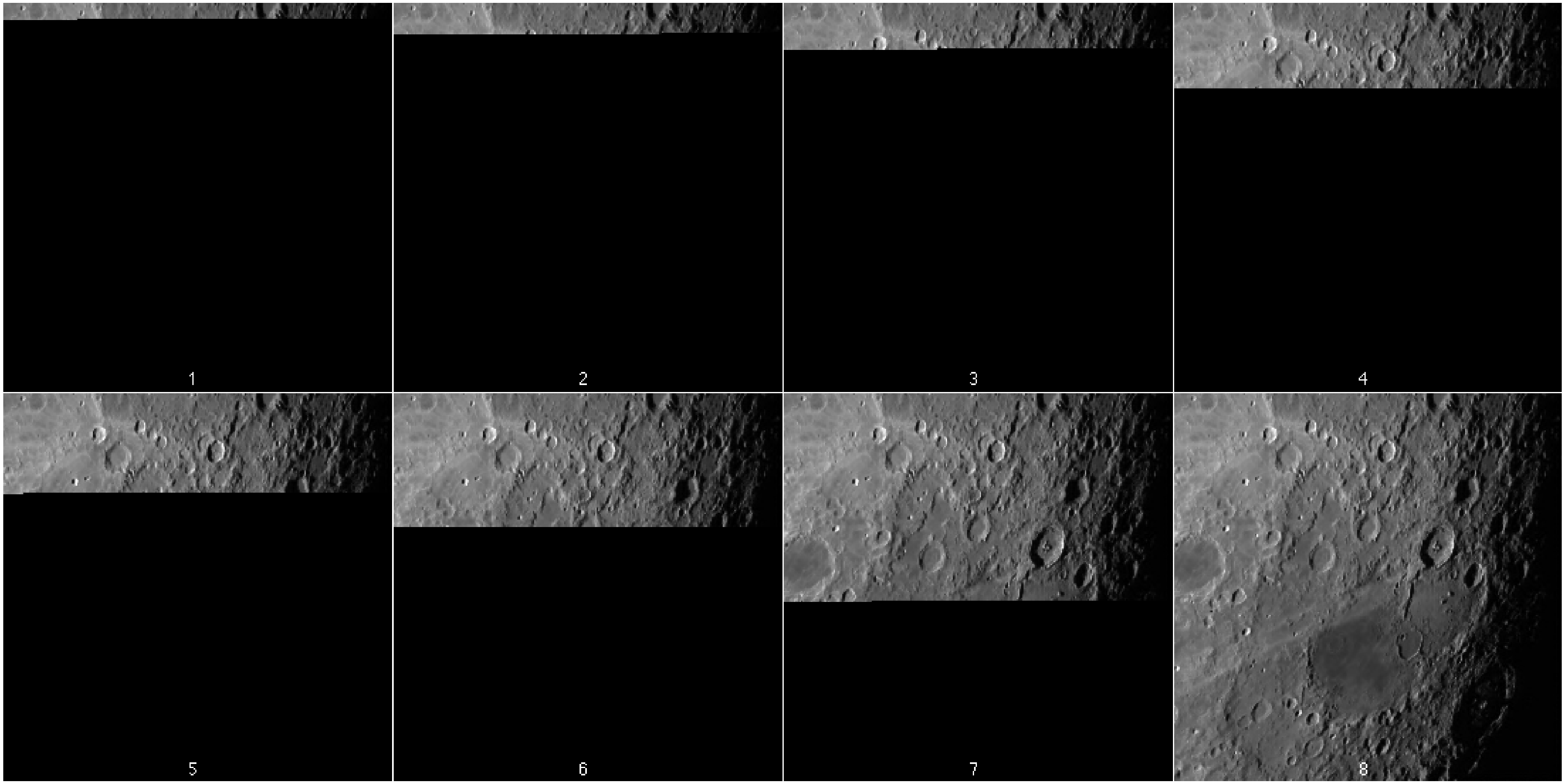
Key Metrics



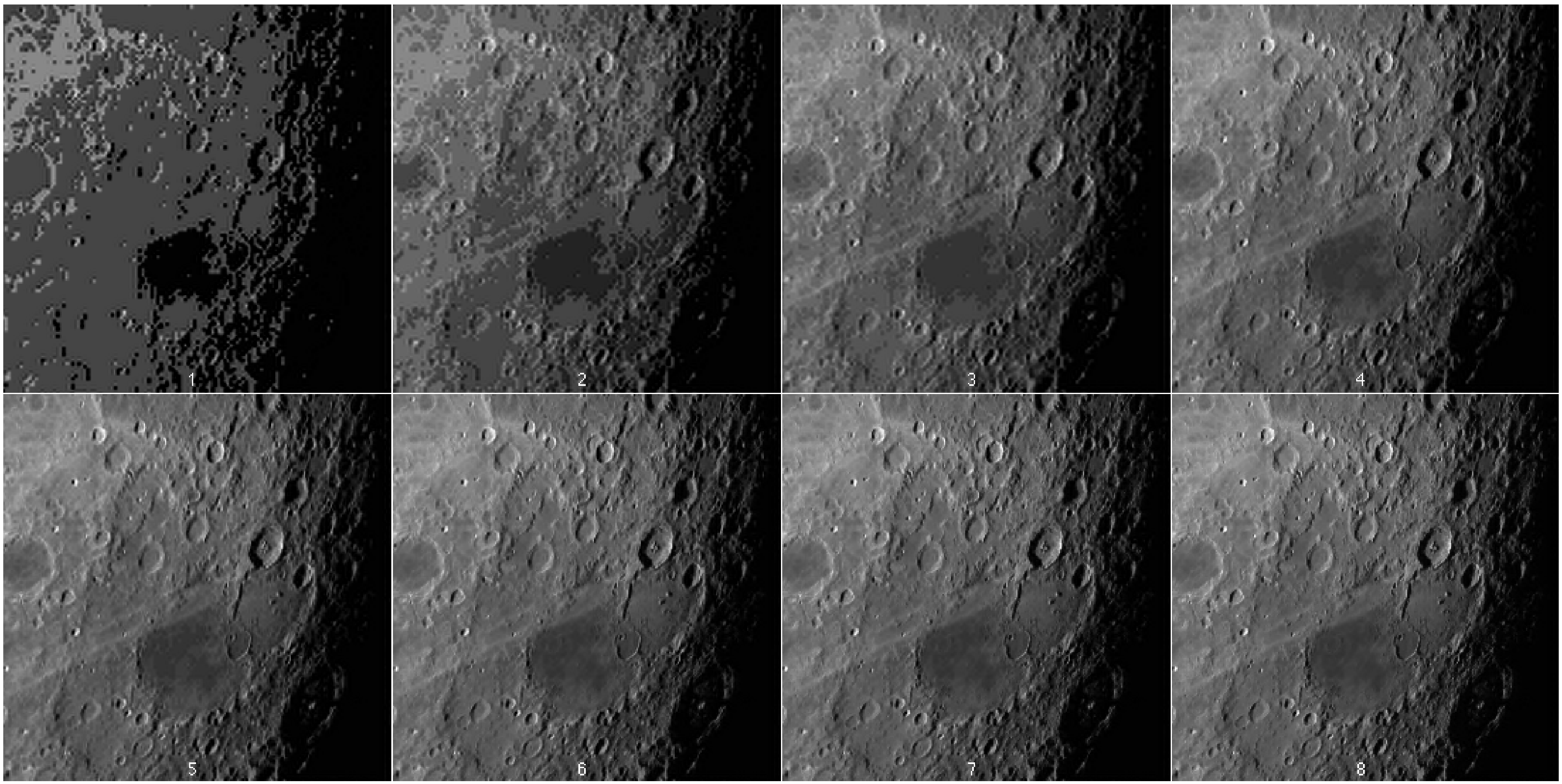


Comparison of progressive subband compression to interlaced GIF (used in Netscape)

Progressive transmission: Raster Scanning



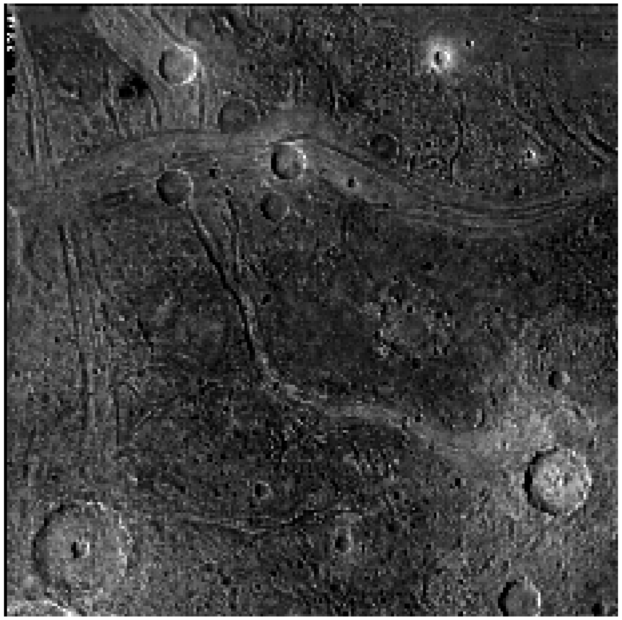
Progressive transmission: Subband coding (Wavelets)

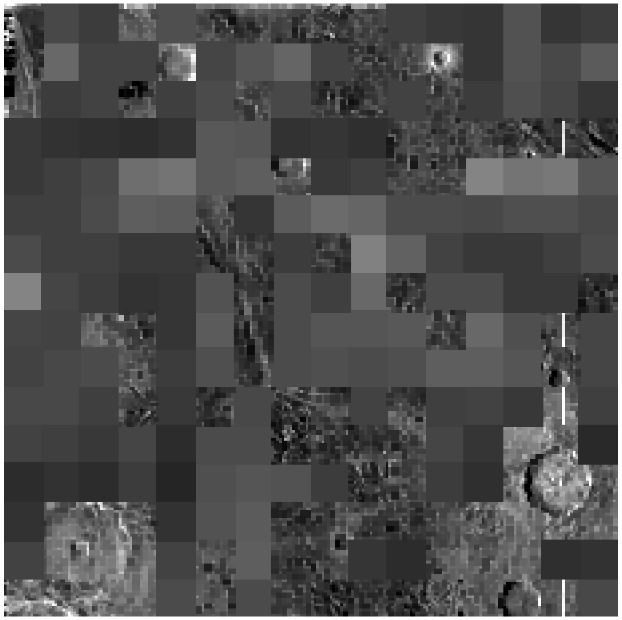


FEATURE-DRIVEN PROGRESSIVE TRANSMISSION

- **Progressive transmission schemes can be based on feature extraction methods --- important data is sent first, at high resolution**
  - **The image is divided into blocks. The "importance" of each block is determined by a measure of pixel activity or feature matching**

ORIGINAL



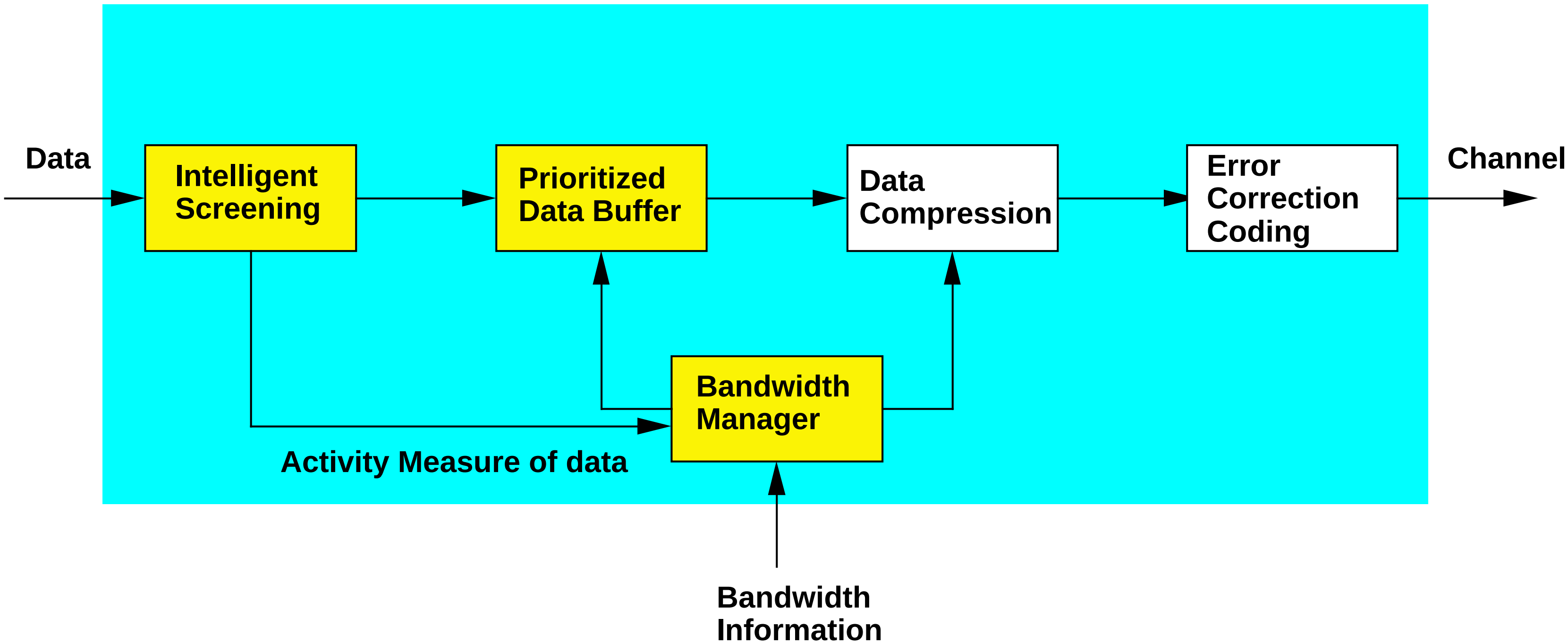


3% OF DATA TRANSMITTED

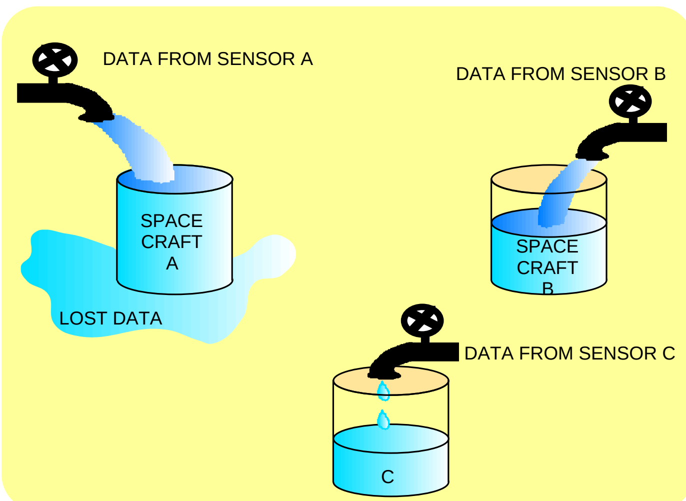
On board data analysis?

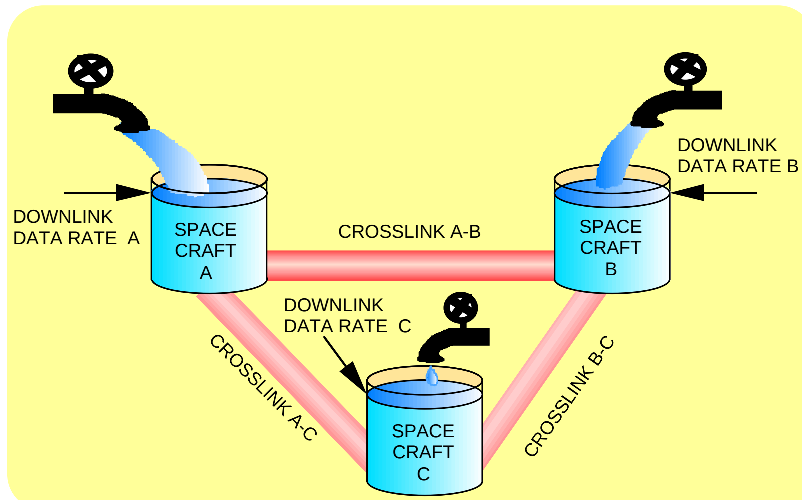
Beyond conventional data compression

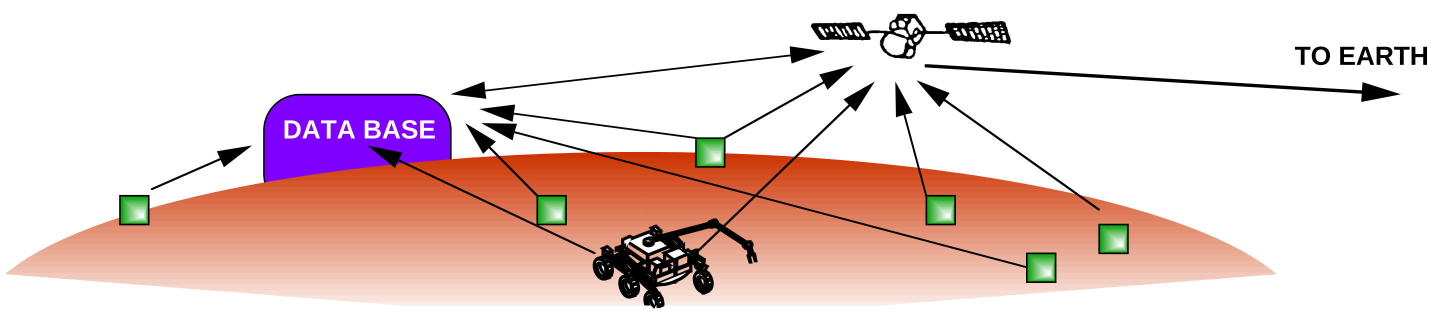
- On-board data screening
- On-board analysis
- Feature extraction



- **Low complexity on-board data screening and analysis (Feature extraction?)**
- **In-flight reprogrammable "data representation" chip (Compression, error correction, etc.)**
- **Low complexity video compression**
- **Space communication protocols that make the spacecraft appear as a node of the network (Build a solar system WEB; Accomplish a virtual human presence in space)**
- **Use crosslinks to balance source data loads with sustainable downlink data rates**
- **Store data from sensors in local data base**







Summary

Low cost, reliable deep-space communication systems are critical to enabling cost effective, small missions.

New approaches are required to meet the challenges of next century missions

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Turbo codes offer the best performance/complexity tradeoff

- We have done extensive simulations, and we have analytic performance bounds
- We have demonstrated turbo codes on a physical channel, and we have space demonstrations in progress
- Turbo codes eliminate the need for Reed-Solomon encoder
- The turbo encoder complexity is similar to that of a convolutional code, plus a 16Kbit interleaver
- Turbo codes can save up to 1 dB in required transmitter power compared to the best concatenated coding systems in use today

Source coding can often save 10-13 dB of power when transmitting images, with excellent reproduction quality.

- Source coding can typically save ~3 dB of power by lossless compression of data
- A in-house developed compression chip could incorporate "windowing" , progressive transmission, and an error containment scheme
- On-board data analysis could drastically reduce downlink requirements